The development of strengths and weaknesses in the sustainable operation of micro-hydropower plants in Nepal: a project process analysis

Joe Butchers
Electrical Energy Management Group
University of Bristol, UK
joe.butchers@bristol.ac.uk

Sam Williamson and Julian Booker
Electrical Energy Management Group
University of Bristol, UK

ABSTRACT

Evaluating the sustainable operation of community owned and operated renewable energy projects is complex. The development of a project (site implementation) often depends on the actions of diverse stakeholders including government, industry and communities. Between these stakeholders and the technology itself, new relationships and responsibilities develop. Furthermore, throughout the project cycle, decisions are made and actions taken that later affect the sustainability of the project. By understanding the impact of critical events throughout the project process, it is possible to find approaches for developing more sustainable community energy schemes. In this paper, the typical project cycle of a micro-hydropower plant in Nepal is used to demonstrate that key events throughout the project cycle affect a plant's ability to operate sustainably. Through a critical analysis of the available literature, policy and project documentation, and interviews with manufacturers, strengths and weaknesses in the operation of plants are found. Examples include weak specification of civil components during tendering, quality control issues during manufacture, poor quality of construction and trained operators leaving their position. Opportunities to minimise both the occurrence and severity of threats to sustainability are identified. For the micro-hydropower industry in Nepal, recommendations are made for specific actions by the relevant stakeholders at appropriate moments in the project cycle. More broadly, the findings demonstrate that the complex nature of developing community energy projects requires holistic consideration of the complete project process.

KEYWORDS

Sustainability, Stakeholder, Community, Hydropower, Mini-grid, Nepal

INTRODUCTION

Community owned renewable energy projects are an option in increasing electricity access in off-grid areas. To deliver electricity services that result in prolonged impact upon lives and livelihoods, schemes must operate sustainably [1]. Literature focused on the assessment of community energy projects has identified that sustainability depends on factors including technical reliability, financial viability and community engagement [2-4]. Typically, as these studies are conducted at the operational stage, they may not be able to evaluate the emergence of these factors during the project cycle. Elsewhere, research has considered the success of national level programs that drive the introduction renewable energy technologies [5-7]. Between these two levels (individual project outcomes and the macro-landscape) is the project process that is determined by the landscape and influences project outcomes. For community-owned projects, this process is dependent on multiple stakeholders with their responsibilities defined by the macro-landscape. The influence of the institutional landscape, the project process, and stakeholder responsibilities are often considered in relation to project success. However, research has tended to consider these areas in isolation, without considering how the institutional landscape shapes the project process and consequently the responsibilities of stakeholders.

To explore this, the case study of micro-hydropower development in Nepal will be considered. There are approximately 3,300 community owned and operated micro-hydropower plants (MHPs) installed in Nepal [8]. The majority have been funded through subsidies administered by the Alternative Energy Promotion Centre (AEPC); since 2006 the *Rural Energy Policy* and *Subsidy for Renewable Energy* have ensured subsidy delivery for renewable energy technologies including micro-hydropower [9]. From the 1960s, development efforts by international donors led to the creation of an in-country micro-hydropower manufacturing industry which still produces most of the generating equipment today [10, 11]. Schemes are initiated by communities who must contribute financially, and physically during construction [12]. Following installation, communities are responsible for owning and operating the plants themselves.

In research focused in Nepal, there is literature that studies both the project landscape and the outcomes of micro-hydropower projects. Several studies have focused on the renewable energy landscape in Nepal [13-17]. In [14, 17], the funding mechanism of renewable energy projects in Nepal is analysed, with particular focus on the success of the subsidy policy in increasing the number of MHP installations. However, challenges including a ‘cumbersome’ delivery process for manufacturers and lack of involvement of the financial sector (due to poor loan recovery and shortage of collateral in rural areas) are identified. In [15] and [16], the success of 2 national level programs that shaped today’s project cycle are considered. Promotion of community involvement, diversity institutions involved (national and local government, and community-based), the focus placed on maintenance and after sales, are identified as success factors. At the project level, research has identified the positive effect upon rural lives [13, 18], factors that contribute to overall project sustainability [19, 20] and the identification of particular technical, social and economic issues that limit sustainability [21-23].

In [12, 24], the Nepali micro-hydropower project cycle has been considered in detail, but there remains an opportunity to understand how and why strengths and weaknesses emerge at the operational stage. The subsidy-based financing of MHPs has resulted in a common project cycle. Within this cycle, certain elements are unique: the nature of the site and the community change from one project to another. However, for every project, the process dictates the actions and responsibilities of various stakeholders. In this paper, available literature, government documentation, and interviews with manufacturing companies are used to understand the roles and responsibilities of stakeholders, and the strengths and weaknesses that have been observed at operational micro-hydropower plants. By evaluating the stakeholder responsibilities throughout the project cycle, it is possible to understand how these strengths and weaknesses develop. Lessons from this case study can be used to inform other community owned renewable energy projects, regardless of technology and location.

METHODOLOGY

In available literature on micro-hydropower plants in Nepal, both operational strengths - factors that enhance sustainability - and weaknesses - factors that threaten sustainability - have often been identified. To understand how these strengths and weaknesses develop during the project process, a methodology which combined analysis of the project process and experiences from the field was used. Firstly, information was collected from the following sources: interviews with 5 manufacturers, policy and supporting government documentation, and available literature. These sources of information were used to identify operational strengths and weaknesses of MHPs in Nepal, and the roles and responsibilities of key stakeholders. A detailed understanding of the project process facilitated evaluation of the events that can lead to strengths and weaknesses. Finally, using these results it was possible to identify opportunities within the project process to tackle weaknesses and reinforce strengths.

Interviews with manufacturers

Semi-structured interviews were conducted with representatives of 5 micro-hydropower companies. The interviews were conducted with senior employees who were responsible for managing the production of hydro-mechanical equipment. Open questions were intended to explore their actions during the design, manufacture and construction phases, and their response to issues that occur in the field. The interviews were conducted in English and recorded[1].

Policy and government documentation

Table 1 lists the policy documentation and guidelines that are openly available from the AEPC. These documents are broadly two types; first, those that are lawful; second, those that are supportive to the policy or provide information to other stakeholders. These guidelines are predominantly advisory documents that recommend good practices. Alongside the freely available government documentation, the AEPC and one of the interviewed manufacturing companies provided a total of 3 tendering documents [25-27]. These documents describe the details of a subsidy eligible project and provide the specification of sub-systems to be quoted for.

Table 1. Policy documentation and guidelines from the AEPC

Title	Year	Overview
Terms of reference for pre-qualification of consulting companies for survey and design of micro-hydropower projects	2013	Provides the criteria that companies must fulfil to be eligible for subsidy.
Guideline for cooperative model of mini-micro hydro projects	2013	Provides background and instructions for the formation of a mini/micro-hydro-cooperative.
Micro Hydro Project Construction & Installation Guideline	2013	Provides detailed instructions for construction of civil structures.
Guideline for Detail Feasibility studies of MHPs	2018	Advises consultants on the standard approach for conducting and reporting on the detailed feasibility study of MHPs.
Renewable Energy Subsidy Policy	2016	Provides the subsidy quantities for several renewable energy technologies.
Subsidy Delivery Mechanism Policy	2016	Outlines the process for administering subsidy to renewable energy projects.
Rural Energy Policy	2006	Ensures the participation of local government and creates a Rural Energy Fund for subsidy delivery.
Micro-Mini Hydro Power Output and Household Verification Guideline	2008	Advises inspectors on how to verify the power output of MHPs at the plant and household level.

[1] Ethical assessment was completed prior to interviews. Interviewees were informed that the information collected was for research purposes only.

Reference Micro Hydro Power Standard	2014	Provides the expected standard for hydroelectric-generating sets, associated civil works, and electrical transmission and distribution lines with capacities up to 100 kW.

Available literature

In Nepal, academic research and project reporting has resulted in a large body of information that considers the operational status of micro-hydropower plants. In [28], the authors of this article conducted a study to consider factors that affect the sustainable operation of plants at 24 sites. The results of that study including interviews conducted with plant managers, operators and consumers have been used to understand strengths, weaknesses, and the roles of stakeholders.

Limitations

The available government literature is comprehensive and gives an indication of the expected best practice throughout the project cycle. Without interviewing staff from national and local government, it is not possible to evaluate the extent to which government documentation is implemented at the project level. Interviews with representatives of manufacturing companies gives an indication of their perspective. Although reputable and established (each with at least 15 years trading), the sample size of 5 manufacturing companies represents less than 10% of companies registered with the Nepal Micro Hydro Development Association [29]. In the methodology, the community perspective has largely been extracted from secondary data. Typically, as project assessments focus on the operational stage, there is a lack of information that describes the views of the community throughout the whole project cycle.

STAKEHOLDERS ROLES AND RESPONSIBILITIES

Community energy projects are dependent on multiple stakeholders and their commitment, collaboration and alignment [30, 31]. During the project cycle, stakeholders' actions and perception influence both the process and the outcome [32]. Experience of the authors and evidence in [12] allows the stakeholders to be categorised into 3 groups:

Institutional: Institutionally, there are multiple stakeholders acting at the national and local levels. Nationally, the AEPC is the government agency that supports renewable energy technology in Nepal. They administer subsidies, provide technical support to individual communities and to regional government offices. Working alongside the AEPC, the Nepal Micro-Hydro Development Association represents 60 of the micro-hydropower companies based in Nepal [29]. They advocate for the interests of these companies and regulate the training that is delivered to plant operators and managers. At the local level, District Coordination Committee (DCCs) are government bodies that represent the interest of local communities within a single district. They usually provide financial support to renewable energy projects that occur within their district. Specifically working to improve access to renewable energy technologies, Regional Service Centres (RSCs) provide an on-the-ground presence to advise and support communities. There are 10 RSCs that cover the 77 districts of Nepal [33].

Community: It may comprise of people from a single or multiple villages who are interested in developing an MHP together. The interests of the wider community are represented formally through a micro-hydro functional group or a cooperative (MHFG/C). In the cooperative structure, financial contribution by the member gives them a share in the MHP, whilst in a functional group the relationship is not formalised. Within this study, the differences between the ownership models is not considered in detail. From the community, several plant operators and a plant manager are chosen who will be responsible for the operation and maintenance (O&M) of the MHP once the installation is complete. It should be considered that members of the community are heterogenous (particularly in status and wealth) [34-36], which affects their perception of, and the actions that they take in relation to the MHP. In addition, there are existing social structures and local dynamics that affect the process of MHP development and its outcomes.

Industry: Within industry, there are technical and financial stakeholders. Consulting companies (CCs) are responsible for conducting feasibility studies, sizing the overall scheme, specifying key components and designing the civil structures. Manufacturing and installer companies (M/ICs) produce or procure the hydro-mechanical and electrical equipment required to develop the project. In Nepal, it is common for companies to perform all three of the technical services of consultation, manufacturing, and installation. Private finance institutions and banks will provide credit to local communities to pay for project costs that are not covered by the subsidy.

A stakeholder "onion" diagram can be used to represent the position of stakeholders in relation to a particular goal [37]. Figure 1 shows the stakeholder groups and the individual stakeholders within this. At the centre of the diagram is the goal that all the stakeholders are working towards. In this context, the goal is the installation and operation of a sustainable MHP. The first level outside of the MHP is the community, the stakeholder group who will directly interact with the MHP upon project completion. The next level is shared between local institutional and industrial stakeholders. These stakeholders design, develop, and facilitate the installation and integration of the MHP within the community; they continue to have some involvement after the installation is complete. The outer level are national institutional stakeholders who administer financial and technical support. For the purposes of this study, the boundary is drawn at this level. However, it should be considered that above this level, the Ministry of Energy, Water Resources and Irrigation and international donors have significant influence over the AEPC's direction and approach [33].

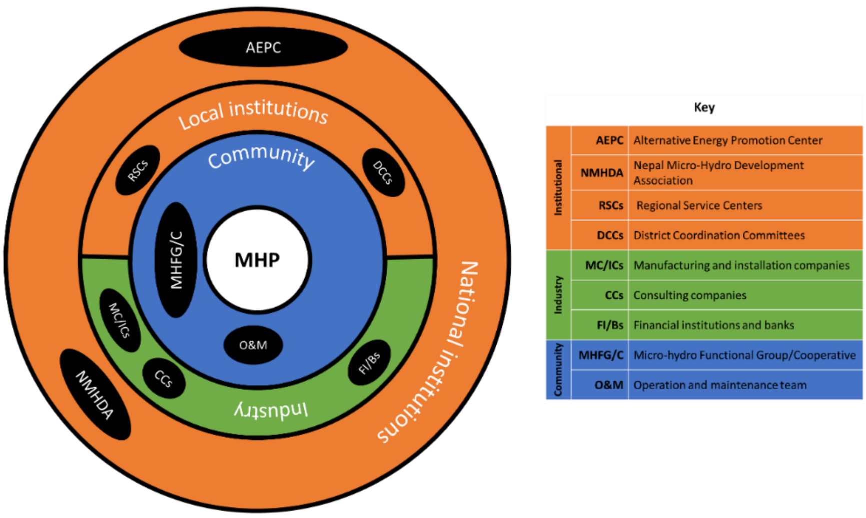

Figure 1. Relationships between stakeholders for the installation and operation of a MHP

The subsidy amount available to the community is determined based on the number of households to be electrified and the overall rated power of the scheme [38]. The districts of Nepal are placed into 4 categories based on their remoteness, with the subsidy amount varying accordingly [38]. Typically, the subsidy covers around 50% of the total project cost; the remaining balance is usually comprised of the community labour and financial contribution, donations from local government, and bank loans [12, 14, 33].

Using the information from the subsidy documentation and supporting literature, it is possible to map the typical actions of the stakeholder groups through the project process. Table 2 shows the key actions required by the stakeholder groups throughout the project process, based on interviews with the manufacturers and [12, 38] . The actions listed are given approximately in sequential order but may occur concurrently. The project process is considered in 5 distinct phases: project initiation, design and manufacture, construction, installation and commissioning, and operation.

Table 2. Actions and responsibilities of stakeholder groups throughout the project process

	Institutional	Industry	Community
Project initiation			Community makes an application to a RSC or the AEPC directly
	RSC carries out pre-feasibility study		
	RSC recommends to AEPC that a detailed feasibility study (DFS) takes place		
	RSC assists in selection of pre-qualified CC		MHFG/C selects pre-qualified company to conduct DFS
		CC conducts DFS and submits report to RSC	MHFG/C submit business plan for the MHP
	RSC and AEPC decide to accept DFS, business plan and approve subsidy		
			MHFG/C begin to collect funds and deposits in a community account
	RSC calls for bids from pre-qualified companies	M/ICs submit bids based on tender documentation	
			MHFG/C select M/IC
	Milestone: payment of 30% instalment	M/IC submit bank guarantee	
			Selection of operators and managers
Design & manufacture		Design by M/IC	
		Manufacture of electro-mechanical equipment by M/IC	
	Milestone: payment of 45% instalment	Equipment delivered to site	
Construction	RSC support civil works and may report to AEPC	M/IC supervises civil works	Civil works by MHFG supervised by MC
Installation & commissioning		Installation by M/IC	
	Power output verified by RSC	Power output testing by M/IC	

	Milestone: payment of 15% instalment	Submittal of power output report	
	Power output verification conducted by a 3rd party		
	NMHDA/CC train operator		Operator receives training
	NMHDA/CC training manager		Manager receives training
Operation & maintenance		M/IC provides assistance in repair and maintenance	Operation and maintenance of system
	Milestone: payment of 10% instalment - Final test of power output after one year		

DEVELOPMENT OF STRENGTHS AND WEAKNESSES

At the operational stage, strengths, and weaknesses in the operation of plants can either support or threaten the sustainability of MHPs. Table 3 lists operational strengths and weaknesses that were identified from the available sources. Within each list, some of the identified strengths and weaknesses may be directly contradictory. In such cases, there is evidence that both can occur. Furthermore, given the dynamic nature of both the technology and the socio-economic landscape it resides in, similar strengths and weaknesses could occur at the same MHP at different times. Elsewhere, relationships may exist between the identified strengths and weaknesses e.g. “Insufficient income to pay for repairs” is connected to “Beneficiaries not paying regularly”. However, as each strength and weakness may develop for a range of reasons and have multiple causal effects, all are deemed worthy of consideration.

Table 3. Strengths and weaknesses of sustainability identified at the operational phase

	Observation	**Evidence**
Weaknesses	Civil structures require repair due to landslides and monsoon	*[28, 34, 39]*
	Poor standard of civil construction	*[12, 28, 39]*
	Misalignment of rotating components	*[28]*
	Poor standard of maintenance	*[21, 28]*
	Insufficient income to pay for repairs	*[28]*
	Uneven distribution of benefits	*[34-36]*
	Conflict within the community – water/land/political	*[28]*
	Community not supportive in repair work	*[21, 28]*
	Reduced power output	*[40]*
	Low load factor	*[12, 17, 39, 41]*
	Problems with tariff collection	*[28, 34, 39, 41]*
	Beneficiaries not paying regularly	*[21, 28]*
	Untrained operator	*[19, 28]*
	Alternative energy sources are available (including grid encroachment)	*[12, 28, 34]*
	Poor functioning of MHFG	*[39]*
	Insufficient flow rate	*[28, 39]*
	Misuse by consumers	*[28]*
	Hydro-mechanical equipment failure	*[21, 39]*
	Low tariff setting	*[12, 28, 34]*
	Distance to repair centres	*[21, 41]*
	Lack of proper accounting	*[17, 41]*
Strengths	Effective collection of tariffs	*[28, 34]*
	Consumers pay regularly	*[28, 41]*
	Plants deliver benefits to community	*[13, 19, 28, 36, 39]*
	Use of electricity meters	*[28, 39]*
	Good sense of ownership amongst community	*[19, 28, 34]*

Trained operator	*[12, 28, 39]*
Trained plant manager	*[41]*
Installed equipment delivers expected rate of power	*[28, 40]*
Supportive community attitude	*[28, 34]*
Good relationship with M/ICs	*Interviews with M/ICs*
Plant funds are correctly managed	*[28]*
MHFG is institutionally strong	*[15, 19, 39, 42]*
Community willing to assist with repairs	*[28]*
High load factor	*[41]*
Range of productive end uses	*[28, 41]*

DISCUSSION

To consider the occurrence of the strengths and weaknesses in Table 3, the project process and stakeholder actions are discussed in relation to the following areas: responsibilities, capacity, quality control and the local environment. Whilst initially discussed in separate sections, the recommendations address some of the overlap and interaction between these areas.

Responsibilities

Throughout the project process, various stakeholders have responsibilities to fulfil. Prior to commissioning, there is significant interdependence between the stakeholders; the completion of responsibilities is reliant on the actions of others. Following commissioning, most responsibilities lie with the community with only occasional support from the M/IC when technical problems occur. During implementation, the responsibilities are usually clearly defined due to the milestones imposed by the subsidy delivery mechanism [38].

When the responsibility is not clearly defined, it can be problematic. For example, the construction of civil structures from the intake to forebay tank is considered to be primarily the responsibility of the community [12]. However, within tendering documentation, "supervision of all civil works" is an item line that M/ICs must quote for [25-27]. Alongside this, RSC engineers may also be expected to support the installation [12] leading to a lack of clarity in accountability, and resulting in higher potential for poorly constructed civil structures.

Many of the responsibilities in the early phases of the project process result in physical outputs that are checked by institutional stakeholders. Alongside this, the actions of the community contribute to a less tangible but vital outcome: the development of collective responsibility for the MHP. Without this, weaknesses like internal conflict, lack of support in repair, and irregular payment are likely to arise. Throughout the project process, certain actions are supportive to fostering the engagement of the community. At the outset, the formation of a MHFG/C aligns the interest of the community, provides representation to marginalised groups and creates a platform for the community to interact with the other stakeholders [29]. The MHFG/C should ensure that all beneficiaries are active during the project, but it is also their responsibility to continue to engage the community after installation. Failure to arrange public meetings and engage beneficiaries leads to a loss of interest [23].

Monetary investment is useful in engaging individuals and as this is expected (at an appropriate level) from all beneficiaries, it is an opportunity for all households to contribute [12]. The community responsibility of the civil construction reinforces individual commitment to the collective cause. At this stage, physical rather than monetary commitment is required with some community members working for at least 6 months. These actions are important in developing a collective responsibility for the "local" plant. The members of the community selected to be managers and operators have a greater responsibility. Technically, if plant operators fail to conduct regular maintenance, the reliability of the plant will suffer [28]. Economically, plant managers must ensure that tariffs are collected regularly, and the plant's income is managed. Without these actions, operational weaknesses develop, and the sustainability of the plant is likely to suffer. Whilst operators and managers are paid for their work [22], a large amount of responsibility is attributed to these individuals.

Capacity

The strengths and weaknesses that occur at the operational stage are often related to the stakeholders' capacity to perform their responsibilities. The institutional framework and some stakeholders (e.g. the AEPC) remain constant from one project to another. For most of the others, their capacity is variable. Amongst both M/ICs and RSCs, there is variation in competence, experience, and manpower. At the outset, the community possess a certain capacity (e.g. financial status, cohesion, and presence of managerially and technically experienced people) but the project process is likely to alter this.

From the community, several people are chosen to receive training for the roles of operator and manager. Their selection by the MHFG/C affects the reliability and financial sustainability of the plant at the operational phase. In some cases, plant operators are selected for social and economic reasons; for example, their land might be in use for the powerhouse, or they are related to someone in a position of authority [34]. In these cases, they may not possess the motivation or capacity of someone chosen through a selection process. Training of managers and operators is required to ensure that they are competent to fulfil their roles. Training for operators is a 22-day course [43] which teaches them how the system operates, regular preventative and corrective maintenance procedures. Training of operators has been common for over 20 years, and has been shown to have a positive impact on the reliability of operational schemes [22]. However, it is common for men to move away to find employment and if a trained operator leaves, the knowledge acquired during training (and informally during the construction and installation phases) is lost [21, 22]. Evidence in the literature suggests that the training of plant managers is not as regularly practiced as operator training. For example [41], in only 43% of managers had been trained, compared to 100% of operators. This is likely to contribute to a range of the observed weaknesses, e.g. problems with tariff collection, low tariff setting, and lack of proper accounting.

During construction, it is the community's responsibility to collect raw material and build the civil works. The interviewed manufacturers explained that poor quality materials are often collected, and that a lack of "trained skilled labour" affects the precision that civil structures are built to. This results in weaknesses in both the quality of the civil structures, and their ability to perform certain functions, e.g. extraction of silt in the de-silting bay [12]. The construction of the civil structures by the community is intended to reduce the overall project cost with only supervision provided by M/ICs [25]. However, according to one interviewed M/IC, as the level of supervision is not dictated the technicians sent to site often lack knowledge and experience of civil elements. Alongside the M/ICs, RSCs are expected to provide ongoing support and ensure that the construction is taking place as planned. Often RSCs do not have enough staff with the relevant experience to provide a consistent presence on site [12].

The actions of M/ICs are largely prescribed by the subsidy process; interviewed manufacturers explained that they do what is required to receive the subsidy. New companies have entered the market, but they focus on cost reduction rather than innovation [12]. The resulting focus on cost means that M/ICs continue to produce similar designs with the same equipment, without looking for opportunities to introduce new manufacturing processes [39] or bought-out components.

Quality control

Quality control processes are important in ensuring that actions have been completed to a required standard. They ensure that for individual projects quality issues can be identified, and that from one project to another, there is replicability. As the project funder, it is the responsibility of the AEPC to implement quality control processes. Manufacturers may conduct some internal QC processes, but their actions are mostly dictated by the subsidy policy. The AEPC has produced an extensive range of guidelines that describe their expectations for how multiple phases of the project process should be completed [44-46]. These are comprehensive examples of good practice that when followed can motivate the creation of operational strengths and limit weaknesses. Alongside the guidelines, there are multiple quality control processes, including several that are directly related to the delivery of subsidies. As the government administers both the documentation and the quality assurance, there needs to be correlation between these two areas.

Outside of the project cycle, the AEPC pre-qualifies both CCs and M/ICs [12, 24]. Pre-qualification is used to assess whether companies possess the human resources and experience required. From the DFS stage, the guidelines demonstrate what should be included in the report [46]. Following the submission of this report, a Technical Review Committee comprising of interdisciplinary stakeholders assess the report, providing an early opportunity to flag technical, social, and economic issues.

The tendering document provides specification of all the sub-systems of the MHP. In the case of some sub-systems such as the turbine and generator this is well defined and can be checked [25]. For the civil structures, whilst drawings are provided the available manpower at RSCs is a barrier to checking regularly [12]. Whilst the design for the civil structures is checked by the TRC, the timing of the final check after installation means that if there is an issue, remediation may be expensive and time consuming. The final subsidy payment depends on a measuring the output performance of the MHP and a visual check of the quality of the installation [47]. Often, the measurement on site results in a value for the overall output power and not the hydro-mechanical efficiency. As such, it is difficult to compare the equipment of manufacturers. Furthermore, the inspection of equipment only occurs on site after it has been installed. A manufacturing or assembly defect that is observed at this stage cannot be rectified. There are standards for the manufactured equipment [48] but these are not referred to within subsidy documentation [38, 49], and it was not possible to find evidence of its use for checking elsewhere within the literature.

During the project process, there are multiple activities that consider the financial viability of the project. Initially, the submittal of a project business plan ensures that the MHFG/C consider the importance of the plant's economic operation. In the DFS, the CC quantifies the consumer willingness to pay and the opportunities for productive end uses in the local area [46]. Observation of the business plan and the assessment of the DFS ensures that institutional stakeholders have considered the financial viability alongside the technical viability. Between the TRC review and training of the plant manager, there are no activities that consider whether the business plan has been implemented.

Local environment

The project process dictates the roles and responsibilities of the stakeholders, but many outcomes are also related to the physical and socio-economic landscape that a project develops in. The geography affects the rated power available, the location and form of the sub-systems, the proximity to the beneficiaries. The socio-economic landscape dictates factors including the wealth of beneficiaries, the opportunities for productive end uses, and existing cohesion within the community. All of these factors influence both the project process and its outcomes.

The physical geography of the site dictates the rated power of the plant and the location of various sub-systems. At the operational phase, these geographical features affect the seasonal water flow and the frequency of land slides and flooding. The DFS considers the geography, with appropriate design as mitigation (e.g. storm traps to mitigate the effect of landslides), but some sites remain at greater risks or require more regular maintenance. The location of the site in relation to the community is also significant. At some MHPs, beneficiaries can be located 6 hours walk from the powerhouse [22]. During the construction, it may be difficult to mobilise community members who are physically far away. At the operational stage, it may impact upon the jobs of operators and managers, and the willingness of community members to pay or participate in meetings and repair works.

The geography and socio-economic status of MHPs is also relevant. In larger settlements, it is easier to connect a greater range and number of productive end uses [22], increasing the plant's load factor and its income. Proximity to the beneficiaries also affects tariff collection. If beneficiaries can pay at a location near to their home, they are likely to pay more regularly. A potential negative impact is that in larger settlements, a higher proportion of people depend on businesses rather than farming for their livelihoods [21]. They may be more resistant to supplying labour during the construction, and for repairs when required [21]. Furthermore, in larger settlements it may be more difficult to mobilise the community collectively. Some MHPs have very scattered beneficiaries. Often communities located away from roads are likely to be of lower socio-economic status. They can struggle to contribute initially and with monthly payments. This can be compounded by the distributed location of their homes which increases the difficulty in collecting tariffs.

Recommendations and lessons learned

In Nepal, the micro-hydropower project process demands active participation and collaboration from multiple stakeholders. The subsidy driven process has led the AEPC to develop documentation that details standards and quality assurance, but the capacity of the institutional stakeholders is a barrier to implementing them rigorously. As a result, the quality of key technical components is often not checked until after they have been installed. The M/ICs interviewed during this study possess the experience and capacity to deliver sustainable MHPs. They are capable of manufacturing equipment to the standard set by the AEPC and supervising the community in the construction of civil works. However, the current subsidy structure means many projects are given to the lowest bidder which drives down the quality of technical elements. The community actions are effective in fostering engagement and result in installed MHPs, but supporting actions are required from stakeholders to ensure that the actions of community result in sustainable projects. Currently, the creation of productive end uses and the financial management of plants is a particular weakness observed widely in the literature. Between different sites, the potential for productive end uses is highly variable and can be identified early in the project cycle. The following recommendations are made that are feasible within the current project structure.

- Training of plant managers is essential and should be practiced at every new installation. It should be conducted locally by RSCs to maximise the number of participants.
- On behalf of the AEPC, independent consultants should use the *Reference Micro Hydro Power Standard* to check the adherence, quality and key dimensions of manufactured and bought in hydro-mechanical equipment before they are dispatched to site.
- Civil structures should be formally checked against the project drawings and AEPC standards by the RSC during construction and before commissioning. A subsidy payment to the M/IC for the supervision of civil works should depend upon it.
- The business plan should include clearly defined actions can be checked by the RSC. Sites with low potential for economic activity should be identified and supported. A second stage business plan which indicates progress should be submitted when the equipment is delivered to site.

In general, for other community energy renewable energy technologies, the established project cycle in Nepal is able to provide a number of lessons. The initiation of the project by the community and their ongoing involvement is effective in fostering ownership. Finding a financial or physical contribution that is appropriate for each household is important. A subsidy driven process provides an opportunity to introduce quality control mechanisms. However, to administer these effectively requires sufficient capacity, and is more effective if administered at the local level. Each project develops within a socio-economic and physical landscape which affect the project process and its outcomes. To operate sustainably, the location of some schemes means that they require greater support during the project process. Proper evaluation of the market opportunities and ongoing support to introduce productive end uses are important in ensuring that plants have high load factors and generate sufficient income. Furthermore, the responsibility of operation and maintenance usually resides with a handful of individuals; they must be properly trained and fairly paid.

CONCLUSIONS

To understand the development of operational strengths and weaknesses requires an understanding of the institutional landscape, project process and stakeholder roles. In this paper, the case study of micro-hydropower plants in Nepal has been used to show that operational strengths and weaknesses can be connected to events that occur within the project cycle. The responsibilities of stakeholders, their capacity to fulfil them, and quality control processes were identified as key factors in determining the development of strengths and weaknesses. For Nepal, recommendations include integrating actions that develop financial viability earlier in the project process, ensuring that quality control processes happen at the correct time, and ensuring that plant managers are correctly trained. Further work will involve conducting a detailed of survey of the capability of manufacturing companies to understand the development of hydro-mechanical defects, and to look for opportunities to improve reliability. For community owned energy projects elsewhere, this works demonstrates the importance of understanding the influence that the project development process, and the interaction of stakeholder responsibilities have upon project outcomes.

ACKNOWLEDGMENT

Joe Butchers' PhD is funded by the Engineering and Physical Sciences Research Council.

REFERENCES

1. Terrapon-Pfaff, J., et al., *A cross-sectional review: Impacts and sustainability of small-scale renewable energy projects in developing countries.* Renewable and Sustainable Energy Reviews, 2014. **40**: p. 1-10.
2. Hong, G.W. and Abe, N., *Sustainability assessment of renewable energy projects for off-grid rural electrification: The Pangan-an Island case in the Philippines.* Renewable and Sustainable Energy Reviews, 2012. **16**(1): p. 54-64.
3. Terrapon-Pfaff, J., et al., *How effective are small-scale energy interventions in developing countries? Results from a post-evaluation on project-level.* 2014. **135**: p. 809-814.
4. Schnitzer, D., et al., *Microgrids for rural electrification*. 2014: New York, USA.
5. Sovacool, B.K., *A qualitative factor analysis of renewable energy and Sustainable Energy for All (SE4ALL) in the Asia-Pacific.* Energy Policy, 2013. **59**: p. 393-403.
6. Palit, D. and Chaurey, A., *Off-grid rural electrification experiences from South Asia: Status and best practices.* Energy for Sustainable Development, 2011. **15**(3): p. 266-276.
7. Bhattacharyya, S.C., *Energy access programmes and sustainable development: A critical review and analysis.* Energy for sustainable development, 2012. **16**(3): p. 260-271.
8. Nepal Micro Hydro Development Association. *MH in Nepal*. [cited 2019 8th July]; Available from: http://microhydro.org.np/mh-in-nepal/.
9. Sarangi, G.K., et al., *Poverty Amidst Plenty: Renewable Energy-Based Mini-Grid Electrification in Nepal*, in *Mini-Grids for Rural Electrification of Developing Countries: Analysis and Case Studies from South Asia*, S.C. Bhattacharyya and D. Palit, Editors. 2014, Springer International Publishing: Cham. p. 343-371.
10. Meier, U. and Arter, A., *Solving problems of micro hydro development in Nepal.* International water power & dam construction, 1989. **41**(6): p. 9-11.
11. Conroy, C. and Litvinoff, M., *The greening of aid: Sustainable livelihoods in practice*. 2013: Routledge.
12. Kumar, P., et al., *Nepal-Scaling up electricity access through mini and micro hydropower applications: a strategic stock-taking and developing a future roadmap*. 2015, World Bank: Washington, USA.
13. Gurung, A., Gurung, O.P., and Oh, S.E., *The potential of a renewable energy technology for rural electrification in Nepal: A case study from Tangting.* Renewable Energy, 2011. **36**(11): p. 3203-3210.
14. Mainali, B. and Silveira, S., *Financing off-grid rural electrification: country case Nepal.* Energy, 2011. **36**(4): p. 2194-2201.
15. Sovacool, B.K., et al., *Electrification in the Mountain Kingdom: The implications of the Nepal power development project (NPDP).* Energy for Sustainable Development, 2011. **15**(3): p. 254-265.
16. Sovacool, B.K. and Drupady, I.M., *Energy access, poverty, and development: the governance of small-scale renewable energy in developing Asia*. 2016: Routledge.
17. Gurung, A., Ghimeray, A.K., and Hassan, S.H., *The prospects of renewable energy technologies for rural electrification: A review from Nepal.* Energy Policy, 2012. **40**: p. 374-380.
18. Legros, G., Rijal, K., and Seyedi, B., *Decentralized Energy Access and the Millennium Development Goals*. 2011: Practical Action Publishing Limited.
19. Bhandari, R., Saptalena, L.G., and Kusch, W., *Sustainability assessment of a micro hydropower plant in Nepal.* Energy, Sustainability and Society, 2018. **8**(1): p. 3.

20. Arnaiz, M., et al., *A framework for evaluating the current level of success of micro-hydropower schemes in remote communities of developing countries.* Energy for Sustainable Development, 2018. **44**: p. 55-63.
21. Barr, J., *Improving Maintenance of Micro Hydropower Systems in Rural Nepal*. 2013, Uppsala University, Sweden.
22. Butchers, J., et al. *A study of technical, economic and social factors affecting micro-hydropower plants in Nepal*. in *2018 IEEE Global Humanitarian Technology Conference (GHTC)*. 2018. IEEE.
23. Winrock International. *In Nepal, Macro lessons for micro-hydro*. 2018 [cited 2020 27 February]; Available from: https://www.winrock.org/in-nepal-macro-lessons-for-micro-hydro/.
24. Alternative Energy Promotion Centre, *Energy To Move Rural Nepal Out Of Poverty : The Rural Energy Development Programme Model In Nepal*, UNDP, Editor. 2012: Kathmandu, Nepal.
25. Alternative Energy Promotion Centre, *Bill of Quantities and Specifications of Electro-mechanical Equipment and Installations Jhumara Khola Micro Hydro Project (11KW) Laha-06, Jajarkot* Alternative Energy Promotion Centre, Editor., Government of Nepal: Kathmandu, Nepal.
26. Alternative Energy Promotion Centre, *Bill of Quantities and Specifications of Electro-mechanical Equipment and Installations Manpang Khola II Micro Hydro Village Electrification Project (11 kw)*. Alternative Energy Promotion Centre,: Kathmandu, Nepal.
27. Alternative Energy Promotion Centre, *Bill of Quantities and Specifications of Electro-mechanical Equipment and Installations Sot Khola Micro Hydro Project (28KW), Surkhet* Alternative Energy Promotion Centre,: Kathmandu, Nepal.
28. Butchers, J., et al., *Understanding sustainable operation of micro-hydropower: a field study in Nepal* Energy for Sustainable Development, in press 2020.
29. Nepal Micro Hydro Development Association. *Members*. [cited 31 March 2020]; Available from: https://microhydro.org.np/members/.
30. Ikejemba, E.C., et al., *The empirical reality & sustainable management failures of renewable energy projects in Sub-Saharan Africa (part 1 of 2).* Renewable energy, 2017. **102**: p. 234-240.
31. Ika, L.A. and Donnelly, J., *Success conditions for international development capacity building projects.* International Journal of Project Management, 2017. **35**(1): p. 44-63.
32. Ruggiero, S., Onkila, T., and Kuittinen, V., *Realizing the social acceptance of community renewable energy: A process-outcome analysis of stakeholder influence.* Energy research & social science, 2014. **4**: p. 53-63.
33. Garside, B., Johnstone, K., and Perera, N., *Moving More Money*. 2019, International Institute for Energy and Development: London, UK.
34. Upadhayay, S., *Evaluating the effectiveness of micro-hydropower projects in Nepal*. 2009.
35. Tulachan, B.M., *Caste-based exclusion in Nepal's communal micro-hydro plants.* Undergraduate Economic Review, 2008. **4**(1): p. 14.
36. Suji, M., *Governing Micro-Hydro as a Form of Common Property: An Analysis of Local Institutions*, in *Social Science Baha & ANHS Annual Himalayan Conference*. 2016: Kathmandu, Nepal.
37. Alexander, I.F. *A Better Fit-Characterising the Stakeholders*. in *CAiSE Workshops (2)*. 2004.
38. Alternative Energy Promotion Centre, *Renewable Energy Subsidy Delivery Mechanism, 2073*. 2016, Government of Nepal: Kathmandu, Nepal.

39. Arter, A., *Micro-Hydropower in Nepal: Enhancing Prospects for Long-Term Sustainability*. 2011, Entec: St Gallen.
40. Khadka, S.S. and Maskey, R.K. *Performance study of Micro-hydropower system in Nepal*. in *International Conference In Sustainable Energy Technologies (ICSET)*. 2012. Kathmandu.
41. Winrock International for Agricultural Development, *Baseline report of Micro Hydro Plants (MHP) selected under Sharing Learning Across Projects: Operating MHPs as Commercially Viable Enterprises*. 2017: Kathmandu, Nepal.
42. Yadoo, A., *Delivery models for decentralised rural electrification: case studies in Nepal, Peru and Kenya*. 2012, London, UK: International Institute for Environment and Development.
43. Nepal Micro Hydro Development Association. *Training Activities*. [cited 2019 6 December]; Available from: http://microhydro.org.np/training-activities/.
44. Alternative Energy Promotion Centre, *Guideline for cooperative model of mini/micro hydro projects*. 2013, Government of Nepal: Kathmandu, Nepal.
45. Alternative Energy Promotion Centre, *Micro Hydro Project Construction & Installation Guideline*. 2013, Government of Nepal: Kathmandu, Nepal.
46. Alternative Energy Promotion Centre, *Guidelines for Detailed Feasibility Studies of Micro-Hydro Projects*. 2018, Government of Nepal: Kathmandu, Nepal.
47. Alternative Energy Promotion Centre, *Micro - Mini Hydro Power Output and Household Verification Guidelines*. 2008: Kathmandu, Nepal.
48. Alternative Energy Promotion Centre, *Reference Micro Hydro Power Standard*. 2014, Government of Nepal: Kathmandu, Nepal.
49. Alternative Energy Promotion Centre, *Renewable Energy Subsidy Policy*. 2016, Government of Nepal: Kathmandu, Nepal.